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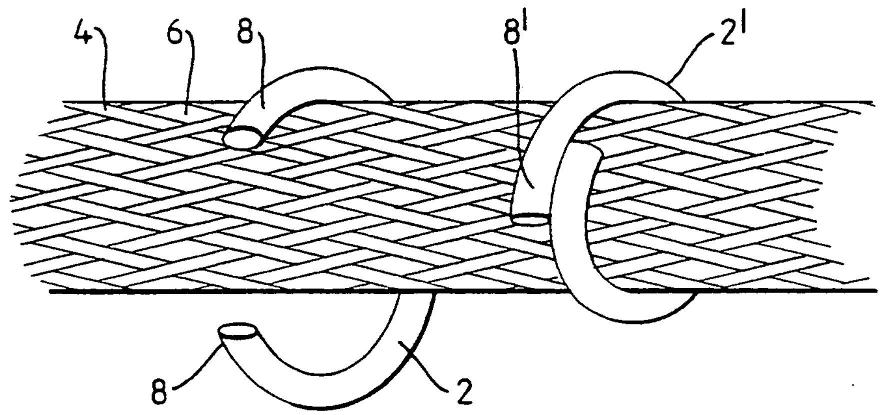

(57) Abstract

A C-shaped clamp (2) for an elongate object (4) is made from a shape memory alloy which exhibits superelastic behaviour. The superelasticity enhances the recoverable strain that can be achieved by the memory metal, and means that the ring may be sufficiently open to allow it to be passed onto the object from the side, or from an angle.

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DESCRIPTION

Clamp

This invention relates to a clamp for an elongate object comprising a split ring.

Clamps are needed for elongate objects for a number of applications, for example to secure a sheath to an elongate object (such as a braid to a cable) or to secure or couple hoses or pipes. Common clamps used for these applications are resilient metal clamps. These exert some force on the elongate object. Generally however they can only be deformed a small amount if they are to exert any securing force on the underlying object, so need to be positioned on the object via one end thereof. This is acceptable for many applications, but is not possible in other applications where sideways entry is required. For these applications it has been usual to employ mechanical clamps for example two half-annular rings which are drawn towards each other by the tightening of screws. These mechanical clamps are clumsy to employ and cannot accommodate any changes in dimensions which may occur, during service, to the underlying object.

We have now discovered that a beneficial new clamp can be made from a shape memory metal (SMA) which exhibits superelastic behaviour.

Materials, both organic and metallic, capable of possessing shape memory are well known. An article made of such materials can be deformed from an original, stable configuration to a second, unstable configuration. The article is said to have shape memory for the reason that it can be caused to revert, or to attempt to revert, from its unstable configuration to its original, stable configuration, i.e. it "remembers" its original shape. Such reversion may be automatic, or caused by the application of heat.

Among metallic alloys, the ability to possess shape memory is generally a result of the fact that the alloy undergoes a reversible transformation from an austenitic state to a martensitic state with a change in temperature. This transformation is sometimes referred to as a thermo-elastic martensitic transformation. An article made from such an alloy, for example a hollow sleeve, is easily deformed from its original configuration to a new configuration when cooled below the temperature at which the alloy is transformed from the austenitic state to the martensitic state.

The temperature at which this transformation begins is usually referred to as M_s and the temperature at which it finishes M_f. When an article thus deformed is warmed to the temperature at which the alloy starts to revert back to austenite, referred to as A_s (A_f being the temperature at which the reversion is complete) the deformed object will begin to return to its original configuration.

However, as used herein, a shape memory alloy includes any alloy which can undergo a reversible deformation with or without a phase transformation, and with or without heat to effect the recovery.

Some memory metals exhibit superelastic behaviour. These materials are defined herein to be those which can undergo recoverable large deformations (greater than 4%) without the onset of plasticity.

Memory metals that exhibit superelastic behaviour may exhibit non-linear superelastic behaviour (also known as pseudoelastic behaviour) or linear superelastic behaviour. With non-linear superelastic (pseudoelastic) materials recoverable strains up to about 8% can be obtained. With linear superelastic materials recoverable strains of about 4-5% can be obtained. These are now discussed in turn.

The non-linear superelastic behaviour results from the formation of stress-induced martensite. When an SMA sample

capable of exhibiting stress-induced martensite is stressed at a temperature above M_s (so that the austenitic state is initially stable), but below M_d (the maximum temperature at which martensite formation can occur even under stress) it first deforms elastically and then, at a critical stress, begins to transform by the formation of stress-induced martensite. Depending on whether the temperature is above or below A_s, the behaviour when the deforming stress is released differs. For temperatures below A_s, the alloy is initially heat treated so the alloy is in its austeniphase. In this case deformation below A_s forms stress-induced martensite and this is stable. If the temperature is above A_s, the stress-induced martensite is unstable and transforms back to austenite, with the sample returning (or attempting to return) to its original shape.

In European Patent Application Publication No. 0140621 (MP873), the disclosure of which is incorporated herein by reference, a nickel/titanium/vanadium alloy having SIM over a wide temperature range is disclosed.

Figures 1 and 2 illustrate the stress-strain behaviour of an alloy which exhibits constant stress versus strain behaviour due to stress-induced martensite.

Figures 1 and 2 illustrate the phenomenon of stress-induced martensite by means of stress-strain curves. In both Figure 1 and Figure 2, the alloy is at a temperature between M_s and M_d so that it is initially austenitic; and it will be assumed for the purposes of this discussion that M_s is equal to M_f, and A_s equal to A_f. Figure 1 shows the case when the temperature is below A_s, so that any martensite formed by the applied stress is stable; while Figure 2 shows the case where the temperature is above As, so that austenite is the only stable phase at zero stress.

In Figure 1, when a stress is applied to the alloy, it deforms elastically along the line OA. At a critical applied stress, σ_M, the austenitic alloy begins to transform

to (stress-induced) martensite. This transformation takes place at essentially constant stress until the alloy becomes fully martensitic at point B. From that point on, as further stress is applied, the martensite yields first elastically and then plastically (only elastic deformation is shown at point C). When the stress is released, the martensite recovers elastically to point D, at which there is zero residual stress, but a non-zero residual strain. Because the alloy is below As, the deformation is not recoverable until heating above As results in a reversion to austenite. At that point, if the sample is unrestrained, the original shape will be essentially completely recovered: if not, it will be recovered to the extent permitted by the restraint. However, if the material is then allowed to re-cool to the original temperature at which it was deformed (or a temperature where SIM behaviour of this type is seen), the stress produced in the sample will be constant regardless of the strain provided that the strain lies within the "plateau" region of the stress-strain curve. That is, for a strain between ε_B and ε_A, the stress will be σ_M. This means that a known, constant force (calculable from σ_M) can be applied over a wide (up to 5% or more for certain Ni/Ti alloys) strain range. Thus, though this resembles the conventional shape memory effect, because the alloy shows SIM and is below A_S a constant force can be achieved.

In Figure 2, when a stress is applied to the alloy, it deforms elastically along line OA, then by SIM along line AB, and by deformation of the martensite to point C, just as in Figure 1. However, the stress-strain behaviour on unloading is significantly different, since the alloy is above A_S and the stable phase is therefore austenite. As the stress is removed, the alloy recovers elastically from C to D; then, at a critical stress, σ_A, the alloy reverts to austenite without requiring a change in temperature. Thus reversion occurs at essentially constant stress. Finally if the stress is removed from the reverted austenite, it recovers elastically along line EO.

The recoverable deformation asociated with the formaiton and reversion of stess-induced martensite has been referred to as pseudoelasticity.

Where the temperature is below A_S, and the material is not initially pretreated to provide it in the austenite phase, the material is always martensitic. In this case, for some materials, deformation causes cold working of the martensite, and results in linear superelastic behaviour. Unlike the non-linear superelastic behaviour (pseudo elastic) the linear superelastic behaviour does not involve a phase transformation.

Figure 3 shows the stress-strain behaviour for a material exhibiting linear superelastic behaviour (loaded to 4% strain and unloaded compared to the stress strain behaviour for a material exhibiting non-linear superelastic behaviour (loaded to 8% strain and unloaded. The non-linear behaviour (corresponding to Figure 2) is shown in dotted lines.

The non-linear behaviour allows greater recoverable strain than the linear behaviour. Also the non-linear behaviour provides a constant force over a large strain range.

Linear superelastic behaviour is thought to result from the interaction between defects from the coldworking process and twins in the martensite. The interaction is thought to cause any migration of the twin boundaries during deformation to reverse during unloading.

An advantage of the use of an alloy that exhibits superelastic behaviour is that larger recoverable deformations can be introduced into articles than would be possible with alloys exhibiting traditional memory metal behaviour. Using the superelastic phenomenom recoverable strains of up to 4%, even 6% or even 8% can be introduced into memory metals.

The present invention uses the enhanced amount of recoverable strain made possible by superelastic behaviour to

provide an article which can be positioned on, or made to contact another object in a certain manner by means of the greater deformation.

A first aspect of the present invention provides a clamp for an elongate object comprising a split ring made from a memory metal which exhibits superelasticity with at least 4% recoverable strain, the ends of the split ring having being moved relative to each other to render the ring recoverable.

A second aspect of the present invention provides a method of fastening a clamp onto an elongate object comprising:

(a) deforming a split ring made from a memory metal which exhibits superelastic behaviour with at least 4% recoverable strain by moving the ends of the split ring relative to each other,

(b) inducing or allowing recovery of the deformation thereby causing the ends of the split ring to move back towards their undeformed position thereby engaging the elongate object.

In one embodiment, the clamp is generally C-shaped, the ends of the C-clamp having been deformed away from each other to render the ring recoverable and to enable the clamp to be positioned sideways onto the elongate object.

The term "positioned sideways onto the elongate object" is used herein to distinguish from positioning the ring over one end of the elongate object. The ring can approach the object from any side and/or at any angle.

In order to be positioned sideways the ring must be sufficiently "open" to allow it to be passed onto the object. It is for this reason that the enhanced recoverable strain made possible by the superelastic behaviour is useful.

The split ring may itself comprise some resiliency.

In one embodiment the clamp is positioned around the elongate object and shrinks on recovery. In this case the distance between the ends of the split ring is preferably approximately the same as the diameter of the elongate object to be clamped (for cylindrical objects).

The clamp may exhibit linear superelastic or non-linear superelastic (pseudo elastic) behaviour.
In one embodiment where the clamp exhibits pseudo elastic behaviour, it is deformed for installation at a temperature below A_s, (having been pretreated so it is austenitic), so that martensite is the only stable form at zero stress, and the clamp exhibits the stress/strain behaviour shown in Figure 1. The ends of the clamp are deformed relative to each other by the formation of SIM. When the clamp has been placed adjacent the elongate object, it needs only to be heated above A_f and allowed to cool to its original temperature, to cause the memory metal to recover and the ends thereof to move relative to each other towards their undeformed position to tighten the clamp into contact with the object. Preferably the clamp contacts the object before complete recovery, i.e. there is some unresolved strain in the clamp. Provided this strain is within the plateau region of the stress/strain curve for the material (between ε_A and ε_B in Figure 1) the clamp will exert a constant force on the elongate object, and this force will remain constant even if the strain is reduced. This is advantageous for certain applications, as explained later.

Where the clamp exhibits pseudo elastic behaviour and is deformed below the As temperature, A_s may be above or below room temperature. In one preferred embodiment As is below room temperature. In this case the clamp may be deformed and strained by SIM formation in liquid nitrogen. Removal of the clamp from the liquid nitrogen, and its consequent warming to room temperature therefore causes transformation to austenite and recovery of the article.

In another embodiment the clamp is deformed for installation at a temperature above A_S, so that austenite is the stable phase at zero stress, and the clamp exhibits the stress/strain behaviour of Figure 2. In this case after deformation of the ends of the clamp relative to each other, the clamp must be held in its deformed position by means of a tool (to prevent automatic reversion to austenite and recovery. After positioning of the clamp on the object the tool is then simply removed allowing the clamp to recover. Since the reversion to austenite takes place at a constant stress, a constant force is exerted by the recovering clamp. Preferably the clamp contacts the object before complete recovery, i.e. there is some unresolved strain in the clamp. Provided this strain is within the plateau region of the stress/strain curve for the material (between ε_A and ε_B in Figure 2) the clamp will exert a constant force on the object.

Where the clamp exhibits linear superelastic behaviour, the clamp (not initially pretreated, so it is and remains martensitic) is defomed for installation at a temperature below A_S, and held in it deformed position by means of a tool. After positioning of the clamp adjacent the object, the tool is removed allowing the clamp to recover. The clamp exerts a continually decreasing force as it recovers in accordance with Figure 3.

The present invention also provides a clamp according to the invention in combination with an elongate object, before and after recovery of the clamp.

The ends of the clamp are deformed relative to each other to allow the clamp to be positioned. The ends may be moved in any direction. They may be moved towards or away from each other. For example, the ends may be moved sideways, generally parallel to the axis of the ring. Another option is for the ends to be moved generally tangentially to the ring. The clamp may vary in cross-section along its length.

Preferably there is more material towards the middle than the ends of the clamp: e.g. it is wider or thicker in the middle. This provides the optimum clamping force.

The ends of the clamp may initially and/or finally be separated from each other, or overlap.

The sideways positioning of the clamp provided by a prefered embodiment, and the clamp's subsequent recovery up to 4%, 6% or even 8% allows the clamp to be used for a number of applications. One typical application is to secure a braid (eg. a screening or earthing braid) to an underlying cable. The underlying cable may comprise a polymer sheath that is subject to in-service creep. Provided there is some unresolved recovery in the clamp (ie it is in the plateau region of the stress/strain curve) the clamp will continue to exert a constant force on the underlying braid in spite of any cable polymer creep. For some applications where a braid is to be attached to a cable the end of the cable is not accessible, so side entry of the clamp is essential. such an application is, for example, where a cable passes through a bulk-head or wall to which it is to be earthed. Previous solutions for such an application have involving the use of mechanical clamps or crimps are more time consuming to apply, and do not automatically accommodate in-service creep of the underlying cable.

Another application for the invention is to repair a braid termination, that is to install a new earthing braid or a termination.

Another application is as a hose-clamp, for example in automobile applications, to connect a host to a tubular outlet.

Embodiments of the invention are now described with reference to the drawings wherein:

Figures 1, 2 and 3 are graphs, previously discussed, illustrating the stress-strain behaviour of an alloy which is deformed by the formation of stress-induced martensite;

Figure 4 is a perspective view of a clamp according to the invention before and after recovery onto a braid and underlying cable; and

Figures 5a and 5b are perspective views of another embodiment of clamp, before and after recovery respectively.

Referring to Figure 4, a memory metal alloy clamp 2, which exhibits stress-induced martensite behaviour is shown in its pre-recovered position on the left of the figure positioned over a braid 4 on a cable 6. The function of the clamp is to secure the braid 4 to the cable 6. The clamp 2' is shown after recovery on the right of the figure. In the pre-recovery position the ends 8 of the clamp 2 are spaced apart a distance A which is substantially the same as the diameter of the cable 6. This enables the clamp to be positioned sideways on the cable, rather than over one end. The clamp may be resilient to enable the ends to be pulled apart, by hand or tool, slightly more, for easy installation.

The ends 8 of the clamp 2 have been deformed away from each other in a direction substantially tangentially to the clamp at a temperature between M_s and M_d and below A_s. Thus the deformation is by the formation of stress-induced martensite, and in the position shown on the left of Figure 3, where there is zero stress on the clamp the stable phase is martensite.

To recover the clamp it is heated above A_s causing the alloy to transform to austenite, recovering some of the deformation strain and exerting a constant force on the underlying braid and cable in accordance with the stress-strain curve of Figure 1. The ends 8' of the recovered clamp overlap to secure the braid 4 tightly onto cable 6 (see right of Figure 4). If, during service, polymeric layers of the cable creep, the clamp will tighten further (the ends 8' overlapping more) by recovering more of the original deformation strain, continuously exerting the

constant force, in accordance with the stress/strain curve of Figure 1.

Figures 5a and 5b shown an alternative form of C-clamp 10 10' before and after recovery respectively. In this case the ends 12 of the clamp are deformed away from each other laterally, in a direction substantially parallel to the axis of the clamp, and come towards each other 12' in the recovered position.

CLAIMS

1. A clamp for an elongate object comprising a split ring made from a memory metal which exhibits superelasticity with at least 4% recoverable strain, the ends of the split ring having being moved relative to each other to render the ring recoverable.

2. A clamp according to claim 1, which is generally C-shaped, the ends of the C-clamp having been deformed away from each other to render the ring recoverable, and to enable the clamp to be positioned sideways onto the elongate object.

3. A clamp according to clamp 1 or 2 which exhibits linear superelastic behaviour.

4. A clamp according to claim 1 or 2 which exhibits non-linear superelastic behaviour (pseudo elastic behaviour).

5. A clamp according to claim 4 which has been deformed at a temperature below A_S to enable it to be positioned sideways on the elongate object.

6. A clamp according to claim 4 which has been deformed at a termperature above A_S, and it maintained in its deformed position by a tool applying a continual stress to enable it to be positioned sideways on the elongate object.

7. A clamp according to any of claims 1 - 6 in combination with the elongate object to which it is to be applied.

8. A clamp according to claim 7 installed on the elongate object, the installed clamp being in contact with the object.

9. A clamp according to claim 5 installed on the elongate object, the clamp having been heated to a temperature

above A_f to cause the memory metal to recover and the ends of the split ring to move back towards their undeformed position so that the installed clamp is in contact with the object.

10. A clamp according to claim 6, installed on the elongate object, wherein the tool has been removed to allow the memory metal to recover and the ends of the split ring to move back towards their undeformed position so that the installed clamp is in contact with the object.

11. A clamp according to claim 9 or 10 wherein when the clamp is in contact with the object it comprises some unresolved recovery.

12. A clamp according to any preceding claim, wherein the clamp has been deformed at least 4%, preferably at least 6%, more preferably at least 8%.

13. A clamp according to any preceding claim, installed onto a braid and underlying cable to secure the braid to the cable.

14. A clamp according to any of claims 1 - 12, installed so as to clamp a hose to a tubular outlet.

15. A method of fastening a clamp onto an elongate object comprising:

(a) deforming a split ring made from a memory metal which exhibits superelastic behaviour with at least 4% recoverable strain by moving the ends of the split ring relative to each other,

(b) inducing or allowing recovery of the deformation thereby causing the ends of the split ring to move back towards their undeformed position thereby engaging the elongate object.

16. A method according to claim 15, wherein the split ring is generally C-shaped and the method involves:

(i) deforming the ends of the C away from each other in a direction to separate the ends of the C, and

(ii) positioning the C-shaped ring sideways over the elongate object.

17. A method according to claim 15 or 16, wherein the clamp exhibits non-linear superelastic (pseudo-elastic) behaviour .

18. A method according to claim 15 or 16, wherein the clamp exhibits linear superelastic behaviour.

19. A method according to claim 17 when dependant on claim 15 or 16, wherein the deformation is carried out at a temperature below A_s, the method additionally comprising:

(c) exposing the positioned ring to a temperature above A_f to cause the memory metal to recover and the ends of the ring to move back towards their undeformed position so that the ring contacts the elongate object.

20. A method according to claim 17, wherein the deformation in step (a) is carried out at a temperature above A_s, or a method according to claim 18 which method additionally comprises:

(d) maintaining the deformation stress on the ring while it is positioned on the object and

(e) releasing the stress thereby enabling the memory metal to recover and the ends of the ring to move back towards their underformed position so that the ring contacts the elongate object.

21. A method according to any of claims 15 - 21 wherein the clamp is deformed at least 4%, preferably at least 6%, more preferably at least 8%.

22. A method according to any of claims 15 - 21 comprising installing the clamp over a braid on a cable and reco-

vering the clamp to secure the braid to the cable.

23. A method according to any of claims 15 - 21 comprising installing the clamp over a junction between a hose and a tubular outlet to secure the tube to the outlet.

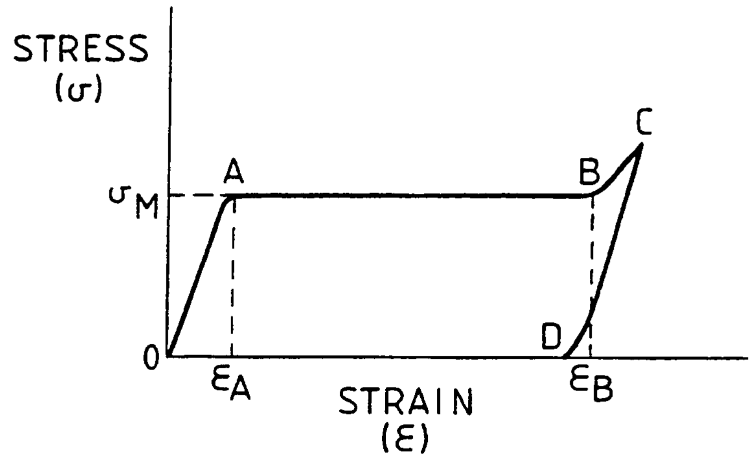


Fig. 1.

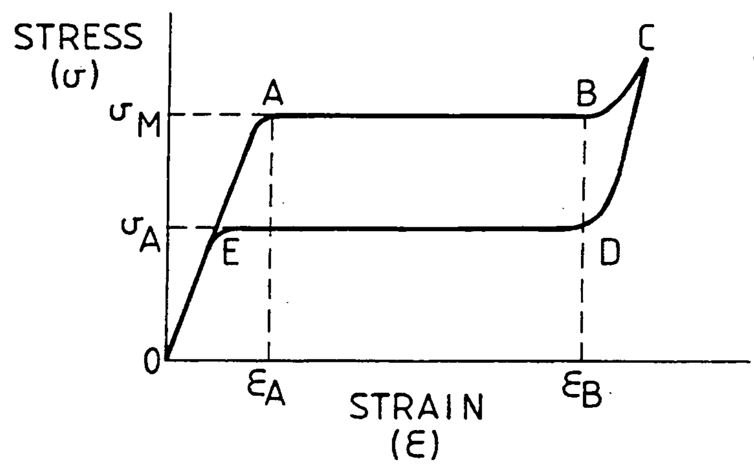


Fig. 2.

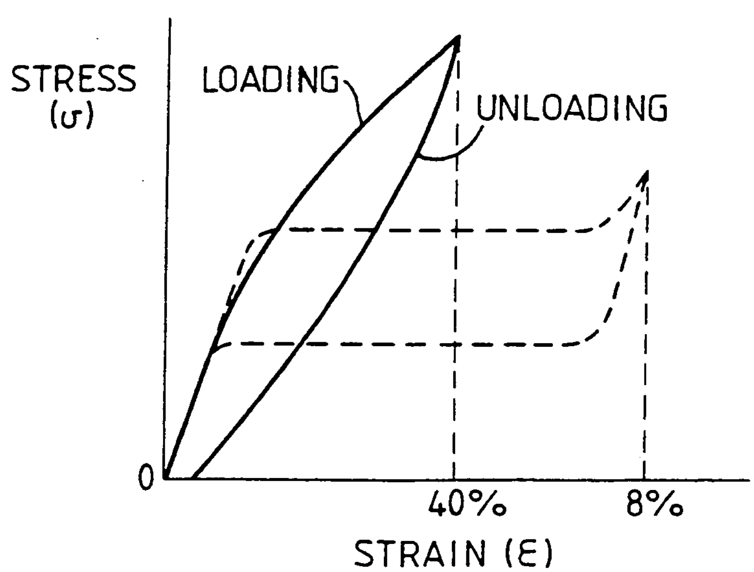


Fig. 3.

Fig. 4.

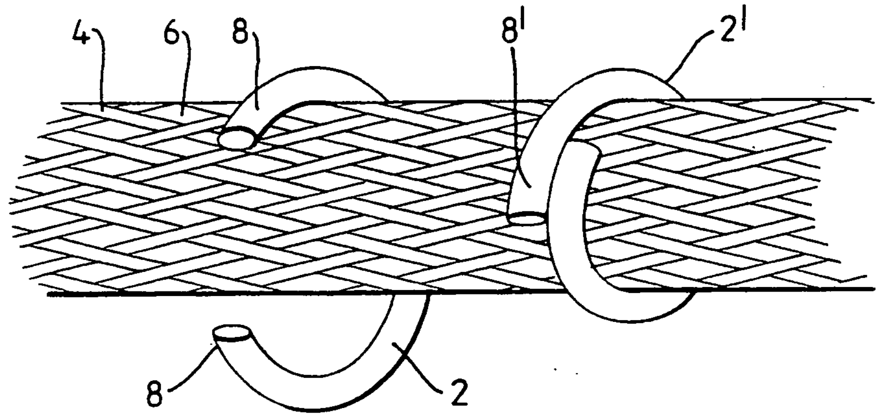


Fig. 5a

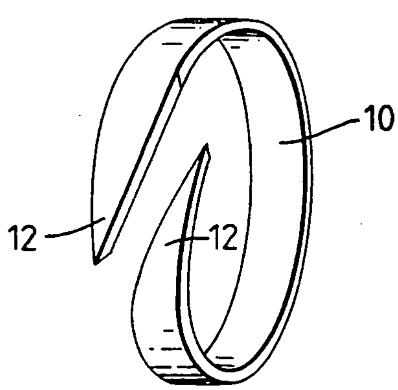
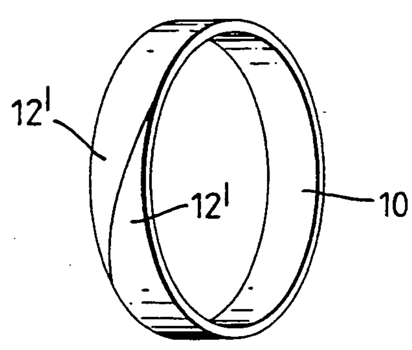


Fig. 5b



SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/00601

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: F 16 B 2/24, F 16 L 33/02,// C 22 F 1/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	F 16 B, F 16 L, C 22 F, C 22 C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	Patent Abstracts of Japan, vol. 12, no. 33 (C-472)(2880), 30 January 1988, & JP, A, 62182241 (HITACHI METALS LTD) 10 August 1987 see the whole abstract	1-3,8,12,15, 16,18,21,23
Y		4,5,17
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A	FR, A, 2557258 (CAMAC S.A.) 28 June 1985 see page 3, line 23 - page 4, line 20; figures 1-3	2
	--	
Y	US, A, 4505767 (RAYCHEM) 19 March 1985 see the whole document	4,5,17
	--	
A	AU, B, 428362 (EMHART CORP.) 29 January 1970 see claims; figures 1,2,5	6,8
	--	
A	EP, A, 0296003 (HUTCHINSON) 21 December 1988	9,10,19,20
	./.	

* Special categories of cited documents: [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
31st August 1989	-9. 10. 89
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	T.K. WILLIS

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No. PCT/GB 89/00601

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	see column 4, lines 15-62; figures 1-4 ------	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 8900601
SA 28970

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 26/09/89
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
FR-A- 2557258	28-06-85	None		
US-A- 4505767	19-03-85	CA-A-	1232477	09-02-88
		DE-A-	3469372	24-03-88
		EP-A,B	0140621	08-05-85
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EP-A- 0296003	21-12-88	FR-A-	2616197	09-12-88

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